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Mechanical Properties of Electrodeposited Brass

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Abstract

Electrical resistivity, density, hardness, wear rate, tensile strength, internal stress, and ductility of electrodeposited 70-30 brass were measured and microstructures were observed. The deposits were obtained from a high speed cyanide bath designed to deposit 70-30 brass. Included are property data for deposits of other compositions obtained from the same bath under conditions other than normal.

I Introduction

Published data on the physical and mechanical properties of electrodeposited brass and other copper alloys have been compiled by Safranak[1]. The data available for brass prior to that compilation was limited to measurements of electrical resistivity and hardness with some observations of the microstructure. The absence of data on tensile strength and ductility led to the investigation reported here and during the course of which measurements were made of electrical resistivity, hardness, wear, density, tensile strength, and significant strain (nominal elongation) at fracture. Although the plating bath was selected for the deposition of 70-30 brass, alloys of other compositions were obtained and data from some of these are included in this report. (Table I).

II Preparation of Plating Solutions and Deposits

A. Solutions

All the deposits for which properties were measured were obtained from a high speed cyanide type bath with a nominal composition of:

CuCN	60 g/l
$Zn(CN)_2$	7.5 g/l
Na CN	120 g/l
KOH	45 g/l

Two baths of this same nominal composition were made up using "plating grade" copper cyanide, "purified" zinc cyanide, reagent grade sodium cyanide, U.S.P. potassium hydroxide, and distilled water.

For purification purposes, each bath was heated to 60°C and 10 g/l of activated carbon was added and kept in suspension by mechanical stirring while holding the temperature for one to one and a half hours. The solutions were filtered through filter paper into the plating tank and them dummied with a corrogated cathode for about 36kC (10 A hr /per litre) at about 50 A/m^2 (5mA/cm^2).

At this point the treatment of the two baths took slightly different courses. Bath A was given a second carbon treatment, filtered, and analyzed for copper, zinc, and free cyanide. To adjust the bath composition, additions were made to a 3 litre portion of the bath. This was given a carbon treatment and filtered into the bath. Deposits 15 through 33 were obtained from this bath. At that time, the carbon treatment was repeated and 7 g/l of KOH were added. Subsequently, deposits 35 through 42 were obtained from this bath. This bath had operated for at least 4.4 MC (1220 A hr) when deposit 42 was completed.

Bath B was not given any further carbon treatment. Minor additions were made to bring the composition to the desired levels. Deposits 43 through 46 were obtained from this bath.

The initial compositions of the bath after purification and just prior to depositing the first test specimens were:

	Bath A	Bath B
Cu	41 g/l	41 g/l
Zn	4.1 g/l	4.4 g/l
"Free cyanide"	49 g/l	45 g/l

The Cu and Zn values were obtained by iodometric titrations, the free cyanide by the silver nitrate titration. The analytical procedures used were designed for plant control purposes and are not highly precise. In effect, the copper and free cyanide concentrations were not adjusted and the zinc concentration was adjusted initially and during use of the bath to give a deposit composition of about 70-30 at 200 A/m^2 (20 mA/cm^2).

Additional information on the composition of the plating bath is given by the results of semiquantitative spectrochemical analyses shown in Table 2. The analyses for the plating baths were of residues from air evaporation of bath samples. One sample, "purified bath" was taken from Bath B after the purification process. The other, "used bath" was taken from Bath A after the last deposit was obtained. The analyses do not show any variation between the two samples. Table 2 also reports an analysis of a brass deposit which shows traces of Ag, Bi, Fe, Mg, and Ni. Silicon present at the 0.01-0.1% range, was the only other impurity detected. These analyses, of course, do not provide information about organic impurities.

A few deposits were also obtained from a bath described by Roehl et al[2]. The actual make-up was CuCN 90 g/l, ZnO 5.3 g/l, NaCN 110 g/l, and NaOH 60 g/l. This bath was given essentially the same purification treatment as Bath B. Deposits from this bath were not tested because of the difficulty of getting sound deposits of the thickness required for property measurements. Good quality thin deposits, for which the bath was designed were obtained. Smooth deposits about 50 μm thick, were produced; but they were quite dark in color. Fig. 1 is a photomicrograph of a cross-section of one of these deposits and it is evident that the top portion of the deposit had a nodular structure.

The anode was sampled at two locations for copper analysis. Cuttings from one edge and drillings, 6 mm deep, from the center showed 67% copper. A semiquantitative spectrochemical analysis is reported in Table 2.

B. Operating Variable

The effect of solution composition on the deposits was not a part of this investigation.

Composition control involved occasional small additions of Cu(CN) or Zn(CN)$_2$ on the basis of analyses of deposits. The free cyanide was determined periodically by the silver nitrate titration. The carbonate content was determined twice. After the last deposit from Bath A, it was found to be 22.5 g/l as NaCO$_3$ and after deposits 43 and 44 from Bath B it was 5.2 g/l.

The solution agitation was roughly controlled by regulation of the flow through a filter-pump unit and through a perforated blind tube. This flow was adjusted to provide optimum uniformity of deposit composition. The temperature uniformity throughout the bath was maintained by this vigorous agitation. It was held at 65 ± 1°C with automatic equipment. The plating current was controlled to ± 5%.

C. Equipment

The plating bath was contained in a rectangular glass battery jar, 30 x 30 cm, filled to a depth of about 38 cm to hold 32 liters of solution. To obtain fairly uniform current distribution, the 20 x 35 cm cathode was held in a cathode box open at the top and towards the anode. The box was 15 cm deep and was constructed of teflon and polypropylene held together with stainless steel screws.

The temperature was automatically controlled with a sensing element in the plating bath which controlled 2 quartz heaters in a water jacket formed when the battery jar was placed in a water filled wooden tank.

Continuous filtration was provided with a commercial filter-pump unit. The cartridges were rated 15 μm. A dynel cartridge was used for deposits 15 to 33 and a polypropylene cartridge was used for deposits 34 to 46. The cartridges were cleaned before use by leaching successively in ethyl acetate, chloroform, and hot 10% sulfuric acid. They were then rinsed with a solution containing 120 g/l of sodium cyanide, and 45 g/l potassium hydroxide and finally with distilled water. The pump and filter housing were constructed of polypropylene and the pump shaft was 304 stainless steel. The unit was immersed in the bath at one side of the tank with the intake at the bottom. The outlet was connected to a polypropylene tube parallel to the cathode and at the bottom of the cathode box about 11 cm from the cathode. The latter tube was closed at the end and there were·two rows of small holes in the tube, one facing the cathode and the other facing upward. The solution emerging from these holes provided the bath agitation.

The anodes virtually covered one wall of the square battery jar opposite the cathode. These were bagged in a polypropylene fabric which had been cleaned in the same manner as described for the filter cartridge.

D. Deposits

The starting cathode was prepared by nickel plating a type 304 stainless steel sheet about 20 x 35 x 0.08 cm. The stainless steel was first polished and buffed with an emery compound. Then it was degreased, pumice scrubbed, rinsed with 1:1 nitric acid, rinsed with distilled water, plated with about 10 μm of nickel from a low pH Watts bath containing 2 g/l of saccharin, rinsed with distilled water, and transferred to the brass plating bath.

The nickel starting sheet was used because of previous experience pre-paring copper deposits for the determination of mechanical properties[3].

After brass plating, the edges of the cathode were trimmed and the deposits were easily separated from the stainless steel. The nickel, which adhered to the starting face of the brass was dissolved anodically at 6V in a solution containing, in parts per volume, 50 of conc. H_2SO_4, 50 of 85% of H_3PO_4, and 5 of water. The removal of the nickel involves the loss of less than 0.2 μm of the initial brass deposit. Most of these brass deposits were 75-100 μm thick although a few were about 40 μm. At least 2 cm of border all the way around each brass sheet was removed and discarded. The specimens required for property measurements were cut from the remaining portion of the sheet.

For wear tests, adherently plated deposits were used. The starting sheets for these deposits were 1010 steel panels, flashed with copper from a cyanide bath, plated with 12 μm of acid copper followed by 10 μm of Watts nickel. The brass was then plated adherently over the nickel surface.

Thickness variation over each deposit was about ± 10%, the same as reported by Lamb et al for copper from cyanide solutions. Current density variation would have been about the same. Variation of composition (% copper) of a deposit ranged from at least ± 0.1 to about ± 3 percentage points with a median of about ± 0.6.

III Measurement of Deposit Characteristics

A. Composition

The composition of each deposit was assumed to be entirely copper and zinc with only trace quantities of other elements. The copper content was determined by the conventional method of electrodepositing the copper on a platinum gauze cylinder. The zinc was not determined except by difference. These determinations are accurate to the nearest 0.05 percentage unit.

One semiquantitative spectrochemical analysis was made of a deposit from Bath A. Table 2 gives a summary of that analyses and shows the major

impurity to be silicon at the 0.01 to 0.1% level. Other impurities are Ag, Bi, Fe, Mg, and Ni. Organic materials are not included in the analysis.

Copper and zinc contents are dependent on agitation, solution composition, and current density. It is practically impossible to keep all of these variables uniform over the surface of the cathode or to reproduce closely from one cathode to another. The variation of composition within a deposit was about ± 0.6 percentage points for copper content. The variation of average composition between duplicate deposits is judged by comparing deposit 23 with 24, 43 with 44, and 45 with 46 in Table 1. The greatest difference is 3% copper.

Deposits 15, 18, and 23 differed by degree of solution agitation, it appears that reducing the agitation leads to a greater copper content.

Early in this investigation, deposits were made at several different current densities. As with the data reproduced by Brenner[4], a plot of copper content vs. current density showed a minimum near 1/2 A/dm^2. Current densities of 1.33 and 2.0 A/dm^2 gave deposits with about the same copper content.

Structure

The photomicrograph of deposit #43 in Fig. 2 shows the typical fine grain microstructure of 70-30 brass deposited at current densities in the 100-200 A/m^2 (10-20 mA/cm^2) range. Deposit #28 was an exception to this in that it had a slightly coarser grain structure near its surface.

The deposits, obtained at current densities of 25 to 75 A/m^2 (2.5 to 7.5 mA/cm^2), had a coarser grain. The maximum grain size was obtained in deposit #29, at 50 A/m^2 (5 mA/cm^2), shown in Fig. 3. These deposits were less than 60% copper.

Deposit #23, 71% Cu, was examined by x-ray diffraction. There was no preferred orientation detected and only the alpha phase was detected. If

another phase had been present at less than the 5% level it would probably have not been observed. The grain size was estimated at 0.025 μm. This method of measuring grain size does not distinguish between twin boundaries and grain boundaries.

B. Internal Stress

The internal stress was measured with a Brenner- Senderhoff spiral con-tractometer, using the precautions described by the inventors[5]. The esti-mated accuracy of individual determinations of stress is ± 2.1 MN/m^2 (0.21 kgf/mm^2) (300 psi).

The stress measurements are summarized in Table 3 for approximately 50 μm deposits. The values given for the % copper in each deposit is subject to two errors. The sample for analysis was obtained by partially dissolving the deposit in 1:1 nitric acid. The top layers would be part of the sample for analysis and the bottom layers would not. To the extent that deposit composition varied with thickness or time, the sampling would not be repre-sentative. Also any selective dissolution of the alloy components would introduce an error.

Another uncertainty to interpretation of these data is the effect of the carbonate content of the bath. For the stress measurements made at 133 A/m^2 (13.3 mA/cm^2), the sodium carbonate concentration was about 22 g/l. For the stress measurements made at 200 A/m^2 (20 mA/cm^2), the carbonate content is estimated to be a little more than half that amount. Everything considered, it appears that the current density from 1.33 to 2 a/dm^2 is associated with a small decrease in internal stress.

Variation of stress with thickness (time) is indicated in Fig. 4 for a typical stress measurement. The stress is directly proportional to the ratio of the dial rotation to the deposit thickness (time). These data indicate that the stress does not vary with deposit thickness. This is in keeping

with the observations of Lamb et al*[3] for small-grain deposits of copper. For large-grain deposits, tensile stress tends to decrease with increasing thickness.

Density of Deposits

The density values reported in Table 4 were determined for 1/2 gram samples cut from brass adjacent to specimens used for the bulge tests. The compositions were determined by gravimetric analysis for copper of each of the entire 1/2 gram samples used for the density measurements. These latter measurements were made using the two liquid hydrostatic method[6]. The float was calibrated with copper specimens. Their density of 8.934 Mg/m^3 had been determined from measurements made by Lamb et al*[3] by the conventional hydrostatic method. Each specimen was measured twice and the reported values have a standard deviation of 0.0017 Mg/m^3 based on the duplicate measurements. The accuracy of the values is estimated to be $\pm$ 0.01 Mg/m^3.

A plot of this data, Fig. 5, indicates, as expected, that the density is primarily dependent on the copper and zinc content of the alloy. For comparison purposes, the plot includes data for wrought alloys taken from the ASM handbook[7].

Electrical Resistivity

The specimens used for measuring electrical resistivity were strips 0.5 cm wide and 15 cm long. These were held in a jig with current contacts at the ends and voltage contacts 9.99 cm apart. A commercial millohmmeter with an accuracy of about 1% full scale was used. It was calibrated with a 1 milliohm standard resistor. Cross-sectional areas were obtained from length, mass, and density, which was either a measured value for the deposit or estimated from the composition of the deposit.

Of the four quantities used to calculate the resistivity, the resistance

measurement was the least precise. This measurement was made at least twice for each specimen. The spread between duplicate measurements was, at most, 0.2 μohm. cm.

Each composition and resistivity value in Table 5 is an average for three specimens cut from the same electrodeposit. The spread between the three specimens was 0.25 to 0.4 μohm. cm for deposits 29, 35, 43, and 44; 1.07 μohm. cm for deposit 32, and less than 0.2 μohm. cm for the others. The spread for deposit 32 is clearly out of line with the other results. All the measurements for the resistivity determinations of 32 were repeated and checked. We note, however, that the 3 specimens of deposit 32 contained 51.0, 52.6, and 53.1% copper. A large change in resistivity could be expected in this range as suggested by Fig. 6.

The bath to bath reproducibility of the data is indicated by deposits 24 and 46 having resistivities of 8.14 and 7.57 μohm. cm respectively and coming from different baths and by deposits 35 and 43 with resistivities of 8.54 and 8.41 μohm. cm.

Fig. 6 indicates how this data relates to that of Andreeva et al[8] and to metallurgically prepared copper-zinc alloys when these data are plotted against composition. The spread of our data and the difference between our data and that of Andreeva et al[8] suggests that factors other than the copper-zinc composition influence resistivity. Grain size and non-metallic impurities could be pertinent factors which depend on the conditions of deposition.

Tensile Strength and Ductility

To obtain tensile strength and ductility data, the hydraulic bulge test[10] was used. The procedures and equipment used were the same as described by Lamb et al[11] with some minor differences. The test specimen was always placed so that the substrate side became the convex side of the bulge. Because a

number of specimens fractured along the edge of the bulge where it met the clamping ring, the radius of that edge was increased from about 3/64 inch to 1/8 inch and the data obtained with the smaller radius was discarded. This change did not completely eliminate fracture at the edge. The rate of loading of the 42.5 mm diameter bulge was reduced to less than 1 lb./5s. This last change did not materially alter the tensile strength and strain data for the 13 deposits retested.

Specimens that fractured along the clamped edge of the bulge are not included in the reported data. The specimens for which data are reported fractured in several different ways: as a slit a few millimeters long, radially from the center to the edge along 6 to 8 different paths, one fracture across the bulge, as an irregular shaped hole several millimeters in length or diameter, and various combinations of these.

Following the practice of Lamb et al[11], the nominal tensile strength calculated on the basis of initial thickness of the test specimen and the significant strain are reported in Table 6. These quantities correspond to tensile strength and nominal elongation obtained by conventional pull tests of brittle materials[11]. The data in Table 6 are averages of the number of specimens indicated. The copper composition is from the analysis of the fractured specimens.

The precision of the tensile strength data may be judged by the spread of measurements on panels of the same deposit which is never greater than ± 6.4% of the mean. Deposits 23 and 24 with average tensile strengths of 1036 and 952 MP were obtained at the same operating conditions as were deposits 43 and 44 with average tensile strenths of 886 and 924 MP. As expected, the significant strain data is not highly reproducible. Individual measurements of specimens from the same deposit varies by a ratio as great as 3.6 to 1. Statistically speaking these strain data are not homogeneous and

the spread is greater than can be attributed to errors in the length measure-
ments used to calculate the strain. This suggests variability of material
within each deposit rather than measuring errors.

For purposes of comparison, 70-30 wrought brass, 68% cold work, has a
tensile strength of about 680 MPa (99,000 psi) and an elongation of 3%.[7]
The tensile strengths obtained in this investigation are significantly greater
than those attributed to Nystrom by Safranak[1]. It is of interest to note
the dependence on thickness shown by Nystrom's data:

μm	psi	MPa
7.5	58,000	410
10.8	69,100	490
13.9	73,900	520

Our values of 600-1100 MPa are for brass of thicknesses of 32 to 98 μm
deposited under somewhat different conditions.

Hardness

Hardnesses of deposits were measured on metallographically mounted and
polished cross sections. A Knoop indentor was used on a commercial micro-
hardness testing machine with a 200 g load. For hardness measurements of
deposits 23, 24, 36, and 37; three specimens were cut from each deposit:
from the top, middle, and bottom sections and from the right and left sides.
Each specimen was measured three times. Since the averages for each specimen
differed insignificantly from each other, only the deposit averages are
reported. For the other deposits, six measurements were made on one specimen
and the average reported for each deposit.

The hardness data is given in Table 1. The reproducibility of these data
may be judged by comparing the following pairs of duplicate deposits, 23 with
24, 36 with 37, 43 with 44, and 45 with 46. The greatest spread is 11 HK_{200}
or 3%. These data do not show a clear relation between hardness and composition

as do the data of Andreeva et al[10] summarized by Safranak[1]. This is partly because the composition of the hardness specimen was not measured directly but assumed to be the average for the deposit. Also our data show the deposits with 45 to 50% copper to be softer than the 65-75% copper deposits; the reverse of that reported by Andreeva et al. This difference is statistically significant and suggests that hardness is influenced by factors other than the copper and zinc content. Grain size and non-metallic impurities could be pertinent factors which are dependent on the conditions of deposition.

For deposits with 68 to 70% copper, the hardnesses are 300 to 350 HK_{200}. These compare to a hardness of 93 Rockwell B (about 200 HK) for 69% cold worked wrought, 70-30 brass[7]. The electrodeposits of other compositions are also harder than the corresponding wrought brass. There is, however, no clear relation between hardness and tensile strength of our electrodeposited material as there is for the wrought material.

Wear Testing

Wear data were obtained with a Taber Abraser on the adherently plated, flat specimen. Several variations of test procedures were explored to find reproducible conditions with which the loading of the abrasive wheels with brass powder would not be objectionable.

It was found to be convenient to break the procedure up into a series of repetitive operations or runs. Each run consisted of dressing the abrasive wheel with 150 grit silicon carbide paper for 50 cycles at a load of 1000 g and running the test piece with the same wheel and a load of either 500 or 1000 g for 5000 cycles for which the weight loss was determined. Initially the test specimen was subjected to 3 runs using a resilient, coarse abrasive wheel (CS-17) at 1000 g to cut in a track on the fresh surface. Then to establish a uniform, abraded surface, 10 runs were made with a resilient, medium abrasive wheel (GS-10) at a 500 g load. The wear rate was then determined by measuring

the average weight loss of the test specimen during 20 runs with the same medium abrasive wheel with the 500 g load.

20 wear runs were made on each of three specimens cut from the same brass plated cathode sheet. Two such sheets were tested along with one test specimen of rolled brass sheet (63% Cu, 35% Zn, 2% Pb). The results may be summarized as follows:

Panel	%Cu	Current Density	Wt. Loss
Rolled Brass	63		8.4 g/1000 cycles
39	72	133 A/m^2 (13.3 mA/cm^2)	10.3
41	70	200 A/m^2 (20.0 mA/cm^2)	7.2

The weight loss data for each panel is an average of three values having a spread of ± 15%. The difference between the two panels is real. The significance of the difference, however, is unknown in as much as this test has not been correlated with service conditions and the reproducibility of the test between laboratories is unknown.

Discussion

The data which would characterize electrodeposited 70-30 brass are given in Table 7. These data were obtained from those deposits with 68 to 72% copper plated at current densities of 130 to 200 A/m^2 (13-20 mA/cm^2). The ranges for each property are not fully explained by variations in current density and copper content, or by measurement inaccuracy, but also reflect other parameters. Such parameters could be deposit impurities, structure, grain orientation, etc. caused by variations of solution agitation; hydroxide, ammonium, carbonate, and free cyanide content of solution; and current distribution. Comparison of these data with those compiled by Safranak[1], reveal differences which may be attributable to differences in solution composition and operating conditions. Differences in hardness, of course, may well be due to difference in methods and techniques of measurement.

The additional data given in Table 1 may be of general interest, but
should not be regarded as representative of electrodeposited brass.

Table 1

Properties of Brass Deposits

Deposit No.	Current Density A/m²	% Copper (average)	Thickness µm	Density Mg/m³ (g/cm³)	Resistivity µ ohm cm	Tensile Strength MP	Significant Strain	Hardness HK200
15	200	78	56	8.64	6.23	1129	0.011	293 (low agitation)
18	200	71	52	8.54	8.03	946	0.008	306 (intermediate agitation)
23	200	71	59	8.53		1036	0.011	315
24	200	71	57		8.14	952	0.009	321
27	100	47	87	8.23	5.04	881	0.010	292
28	150	78	75		6.39	1088	0.025	277
29	50	48	91		4.11	621	0.034	155
30	125	69	82		8.26			307
31	75	48	94		4.77	936	0.011	285
32	25	52	97	8.29	5.45	734	0.008	251
34	133	84	59		8.58	955	0.068	(low KOH concentration)
35	133	69						
43	133	68	76	8.50	8.41	886	0.005	349
44	133	65	45	8.42	8.38	924	0.008	355
45	200	72	60	8.54	7.91			351
46	200	70	31	8.50	7.57	1005	0.009	340

Table 2

SPECTROCHEMICAL ANALYSIS FOR METALLIC IMPURITIES

Element	Residue from Evaporation of			
	Brass Anode	Purified Bath	Used Bath	Brass Deposit
Ag	.001-.01	<.001	<.001	<.001
Al	--	.001-.01	.001-.01	--
Bi	<.001	--	--	<.001
B	--	.1-1	.1-1	--
Ba	--	.01-.1	.01-.1	--
Ca	--	.01-.1	.01-.1	--
Cu	>10	>10	>10	>10
Fe	.001-.01	.001-.01	.001-.01	<.001
K		1-10	1-10	
Mg	<.001	--	--	<.001
Mn	--	<.001	<.001	--
Na		>10	>10	
Ni	<.001	--	--	<.001
Si	.01-.1	.1-1	.1-1	.01-.1
Ti	.001-.01	--	--	--
Zn	>10	1-10	1-10	>10

NOTE: >, greater than; <, less than; --, not detected; values given as weight percent.
Other elements checked for but not detected include As, Au, Cd, Ce, Co, Cr, Ga, Ge, Hf, In, Ir, La, Mo, Nb, P, Pb, Pd, Pt, Re, Rh, Rv, Sb, Sc, Sn, Sr, Ta, Th, V, Y, Yb, Zr.
U and W were checked for in the anode and deposit. Hg, Os, Sm, Te, and Tl were checked for in the bath residue.

Table 3

INTERNAL STRESS

Composition of Deposit		Current Density	Stress		
	Cu (%)	A/m^2	psi	kgf/mm^2	MPa
	70	200	11,900	8.4	82
	69	200	11,600	8.2	80
AVE:	69.5	200	11,800	8.3	81
	69	133	12,900	9.1	89
	71	133	13,600	9.6	94
AVE:	70	133	13,300	9.4	92

1 A/m^2 = 0.01 A/dm^2 = 0.001 mA/cm^2

Table 4
Density

Deposit	Cu (%)	Density Mg/m^3 (g/cm^3)
27	47.3	8.23
32	50.6	8.29
44	63.3	8.42
43	68.6	8.50
46	69.0	8.50
18	70.8	8.54
23	70.9	8.53
45	71.8	8.54
15	77.4	8.64

Table 5

Resistivity

Deposit No.	%. (Cu) Average	Average Resistivity μ ohm cm
15	77.7	6.23
18	70.0	8.03
24	70.3	8.14
27	46.7	5.04
28	77.4	6.39
29	47.7	4.11
30	69.2	8.26
31	47.4	4.77
32	52.2	5.45
35	69.0	8.58
43	67.7	8.41
44	65.7	8.38
45	71.6	7.91
46	69.9	7.57

Each value is an average of the data from each

of three specimens.

Table 6

Tensile Strength and Significant Strain

Tensile Strength

Deposit No.	% Cu	MP	PSI	δ	Number of Specimens Measured
15	78.4	1129	163,700	.011	3
18	71.6	946	137,200	.008	5
23	70.8	1036	150,300	.011	3
24	71.1	952	138,000	.009	2
27	47.7	881	127,800	.010	5
28	77.8	1088	157,800	.025	5
29	48.7	621	90,000	.034	3
31	48.0	986	143,000	.011	1
32	51.0	734	106,500	.008	2
34	83.7	955	138,500	.068	4
43	69.1	886	128,500	.005	2
44	65.4	924	134,000	.008	1
46	70.8	1005	145,750	.009	4

Table 7

Properties of Electrodeposited Brass 68-72% Copper

Resistivity	7.6-8.6 μ ohm-cm
Density	8.50-8.54 Mg/m^3
Hardness, HK_{200}	306-351
Tensile Strength (nominal)	886-1036 MPa
Elongation (significant strain at fracture)	0.5-1.1%
Internal Stress	81-94 MPa

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25μm

Fig. 1.

Photomicrograph of cross-section of brass deposit from bath described by Roehl. Deposit about 50 μm thick.

25μm

<u>Fig. 2</u>.

Cross-section of deposit #43. Thickness: 71 μm.
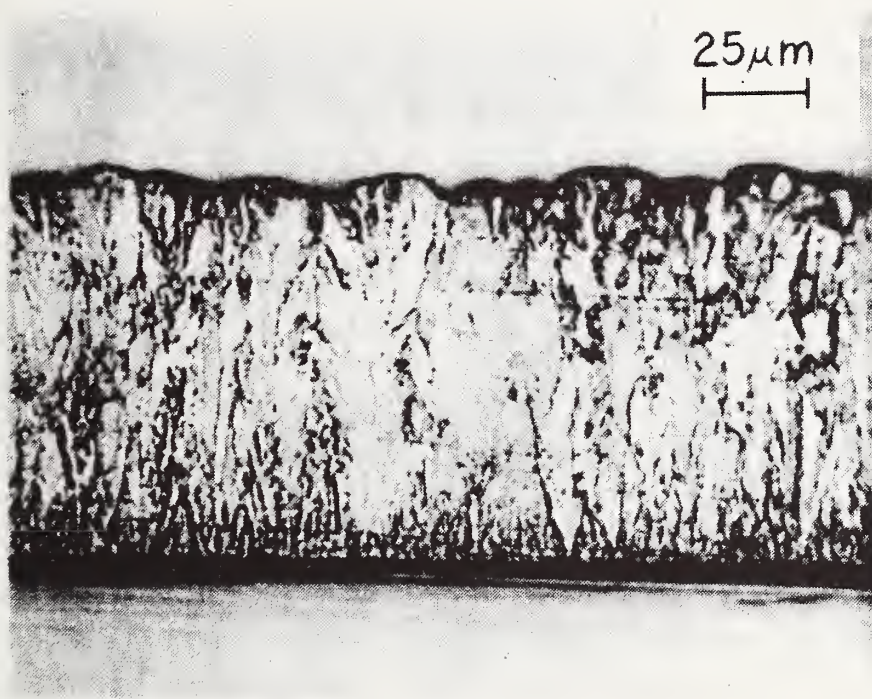
Fig. 3.

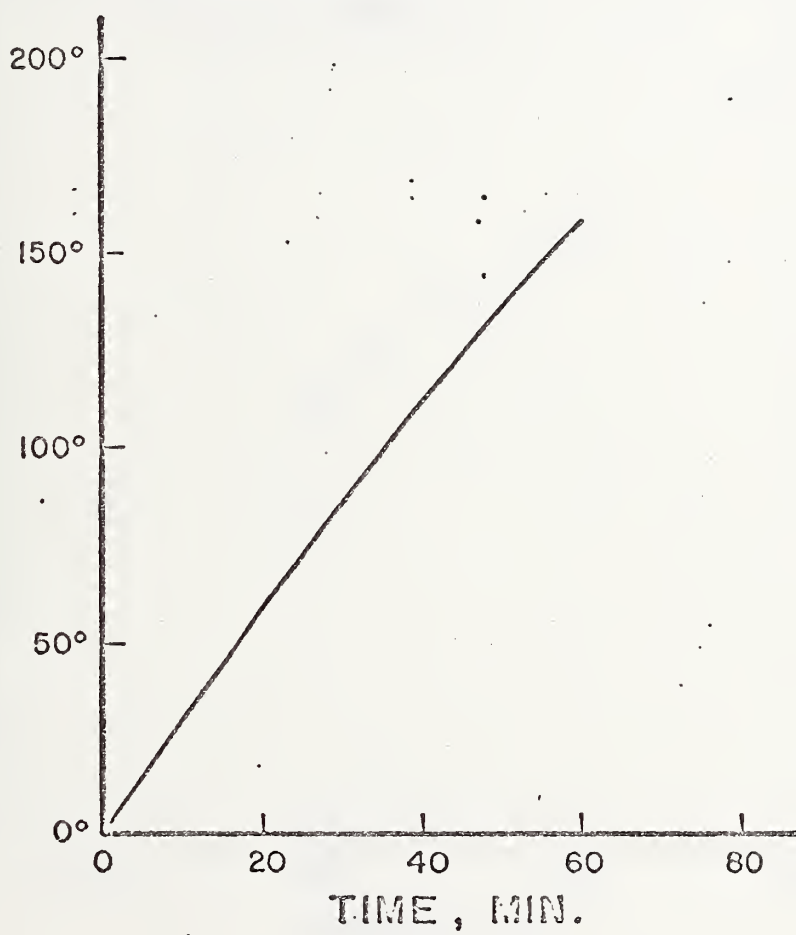   Cross-section of deposit #29.   Thickness: 79 μm.

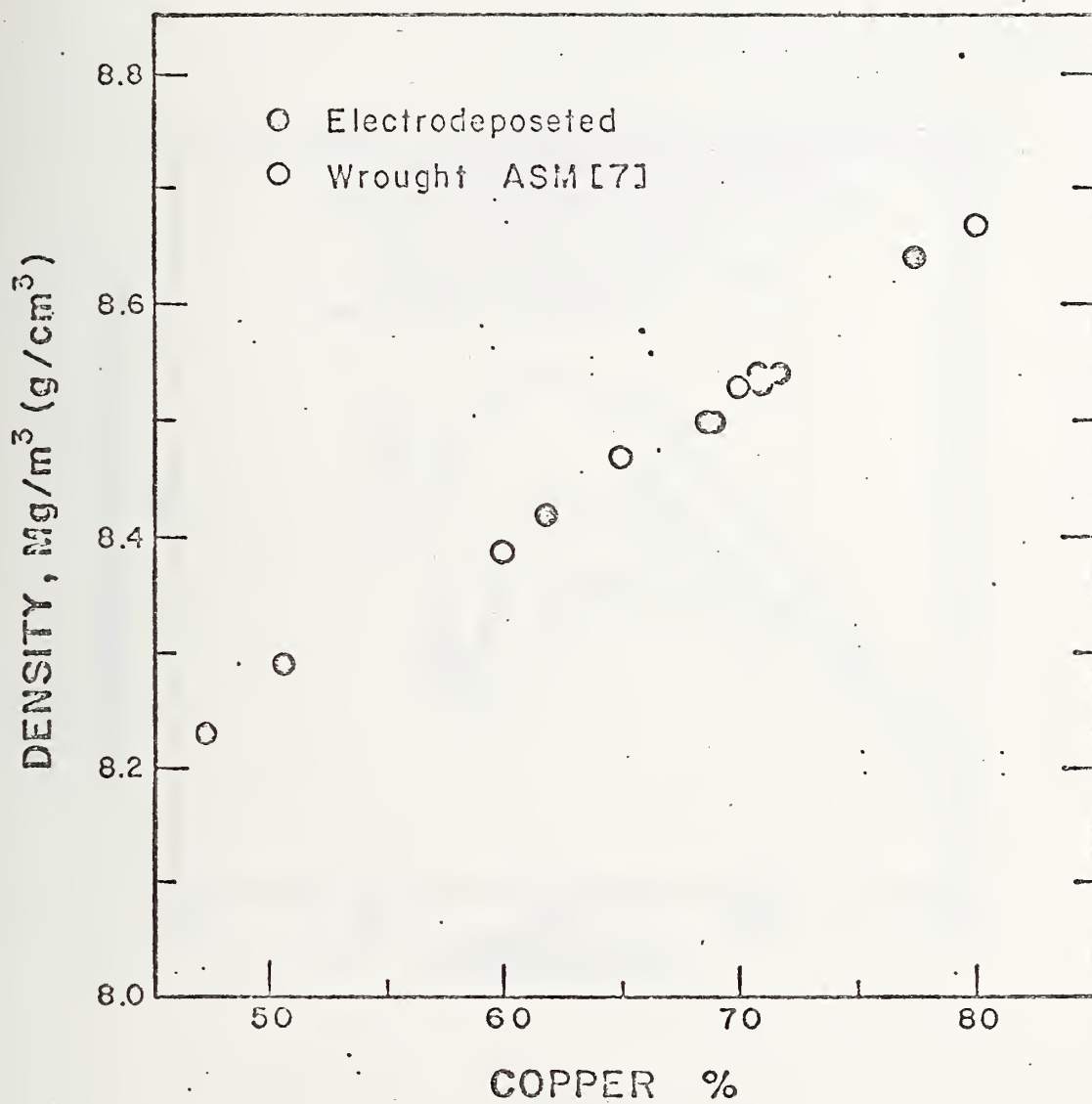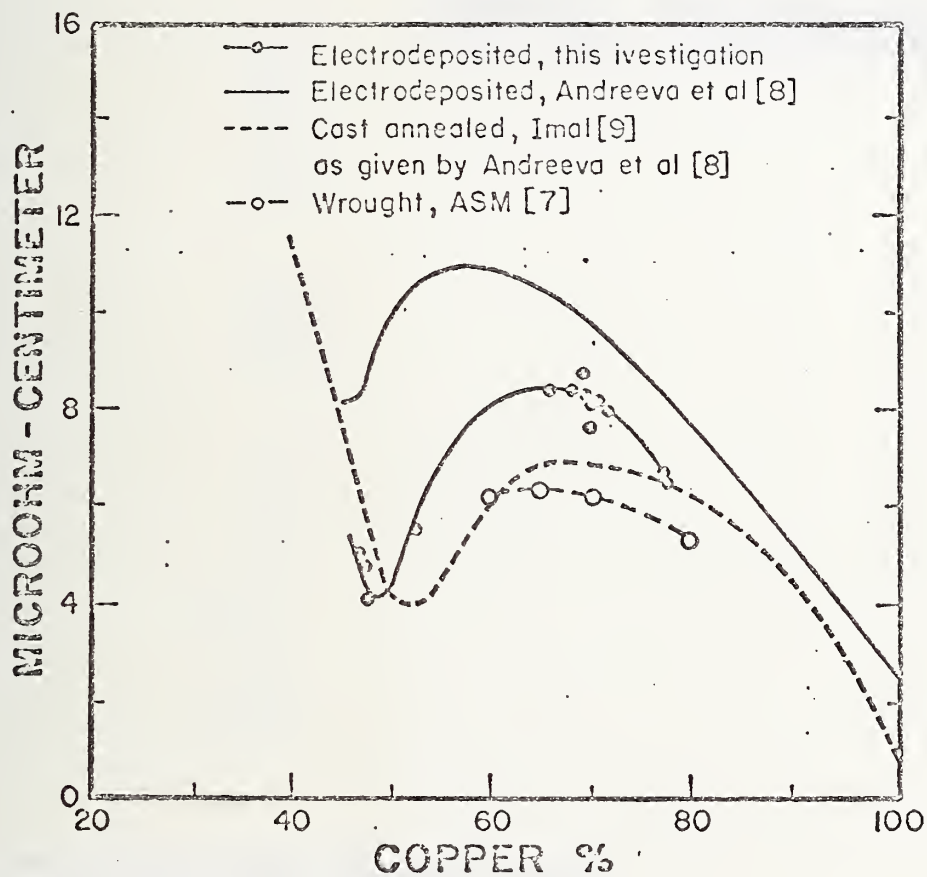Figure 4.
Variation of internal stress with time of plating.

Figure 5.
Density vs. Composition.

Figure 6.
Resistivity vs. Composition.